MULTI-DISCIPLINARY ANALYSIS OF A SMART MATERIAL CANARD ACTUATOR USING HIGH PERFORMANCE COMPUTING

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ABSTRACT

The U.S. Army Research Laboratory is currently investigating smart munitions technologies as a means of improving the lethality and accuracy of future generations of munitions. One of the focuses of the current effort is the development of integrated multi-disciplinary design technologies such as structural dynamics, computational fluid dynamics (CFD), rigid body dynamics (RBD) and guidance, navigation and control (GN&C). These multi-disciplinary design technologies allow complex munition systems to be studied and visualized within high-performance computational environments to determine the nonlinear interaction of critical engineering parameters using high-fidelity physics. This allows detailed design trades to be performed on system subcomponents, resulting in reduced development costs and higher performance munitions.

1. INTRODUCTION

As part of this effort, the performance of a smart material canard actuator for a canard controlled smart munition (Figure 1) has been investigated using a multi-disciplinary design approach. The forward mounted canards (or control fins) provide a means of controlling the flight trajectory of the munition. The canard configuration is similar to conventional canards except that the actuator that allows the canard to deflect is embedded inside the canard structure. This is accomplished using piezo-electric smart materials that change shape in response to an applied electric charge.(Rabinovitch and Vinson, 2003) By placing the actuator within the canard structure, the critical weight and volume requirements for the actuator are significantly reduced.

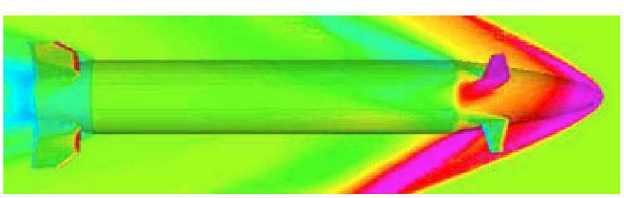

Figure 1. Smart cargo munition.

2. COMPUTATIONAL APPROACH

In the current phase of the investigation, the time-dependent dynamic response of the smart material canard actuator has been investigated by applying a coupled CFD/GN&C/RBD/structural model to the candidate configuration. The CFD approach allows the instantaneous aerodynamic torque acting on the canard surface to be accurately determined due to the combined effects of angle of attack, canard deflection, and canard deflection rate. Using the instantaneous aerodynamic torque derived from CFD, the canard motion is subsequently determined from solutions of the rigid body equations of motion of the canard structure, the control laws, and the structural modeling of the piezoelectric actuator in a fully coupled manner.

The flow field about the canard-controlled smart munition has been predicted using an overset grid approach that allows relative motion between bodies in close proximity.(Meakin, 1991; Renze, et al. 1992), The method utilizes a near-body grid system of interconnecting grids that conform to various pieces of the bodies surrounded by an outer off-body Cartesian-based grid system. The interconnecting near-body grids overlap and intergrid connectivity is established using a Chimera overset gridding approach. This significantly reduces the demands on grid generation, as each body component can be gridded independently. The outer off-body Cartesian grid system encompasses the near-body grid system and extends to the outer boundary of the computational domain. The off-body grid system typically consists of several levels of grid refinement, with the most refined grids in proximity to the near-body grids and increasingly less refined grids further away from the body. Solution of the compressible Reynolds-averaged Navier-Stokes equations is accomplished using a three-factor diagonal-implicit, first-order accurate time-stepping scheme that employs second-order accurate central differencing in space.

Using an interface provided within the code, the original 6-degree of freedom (DOF) RBD capability was replaced with a special 6-DOF RBD and GN&C capability. The GN&C capability employs an element-based approach for constructing complex control schemes

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **00 DEC 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Multi-Disciplinary Analysis Of A Smart Material Canard Actuator Using High Performance Computing**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Research Laboratory Aberdeen Proving Ground, MD 21005**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001736, Proceedings for the Army Science Conference (24th) Held on 29 November - 2 December 2005 in Orlando, Florida. , The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**2**	

and includes common fundamental control elements such as summers, comparators, gains and integrators, as well as more advanced components such as IMUs. For the current application, the GN&C capability allows control schemes for the canard actuator to be easily constructed so that the canard deflection can be controlled. The results from analysis based on classical plate and lamination theories and constitutive modeling of the piezoelectric material has been used to characterize the structural response of the smart material actuator. To accomplish the integrated multi-disciplinary computations in a timely manner, solutions were obtained on an SGI Origin 3800 using 12 processors. Scientific visualization was utilized to view and analyze the results.

3. RESULTS

Using the multi-disciplinary approach, the time-dependent response of a smart material actuator concept has been evaluated. Figure 2 shows that the open-loop response of the system produces canard deflection angles that are different than the commanded canard deflections and are completely dependent on the local flow conditions. This is due to the interaction of the externally applied aerodynamic loads with the flexible structure that is inherently part of the smart material actuator design.

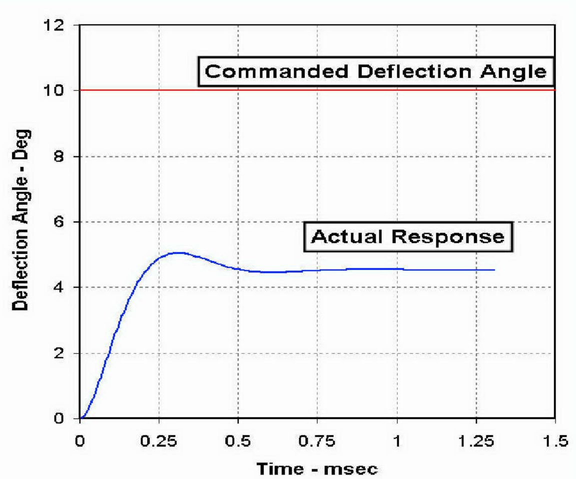

Figure 2. Open loop response of canard.

A closed-loop feedback control law was then implemented and tested using the multi-disciplinary approach. Figure 3 shows that by properly tuning the gain in integral control-law, the proper response of the canard to the commanded deflections can be obtained. The results show that a time-accurate approach which is able to predict the rate-dependent aerodynamics is required to properly tune the gain on the integral controller. The results also show that if the gain is not properly selected, the response of the canard is either too slow or oscillatory and possibly divergent.

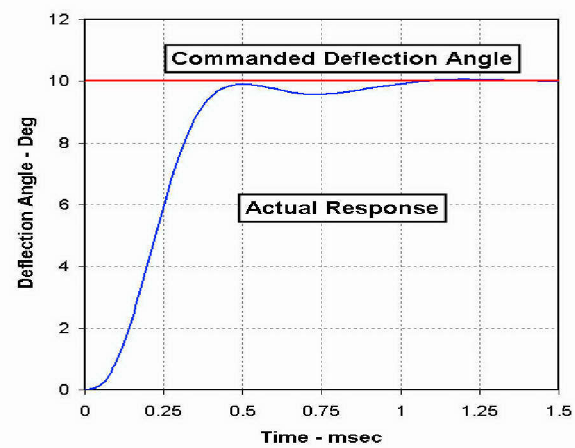

Figure 3. Closed loop response, I_c=10000/s

CONCLUSIONS

Using a multi-disciplinary approach, the time-dependent response of a smart material actuator concept has been evaluated. The results show that a closed-loop feedback control law is required to produce the desired deflection because of the interaction of the externally applied aerodynamic loads with the flexible structure that is inherently part of the smart material actuator design. The multi-disciplinary approach provides a means of properly designing and tuning the control law to provide optimal control of the canard actuator system. This demonstrates the utility of the approach as a sophisticated but cost-effective means of evaluating control strategies for future munition systems.

ACKNOWLEDGMENTS

This work was supported in part by a grant of computer time from the Department of Defense High Performance Computing Major Shared Resource Center at the U.S. Army Research Laboratory.

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